METHOD AND SYSTEM FOR OPERATING A LASER SELF-MODULATED AT ALKALI-METAL ATOM HYPERFINE FREQUENCY

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of U.S. patent application Ser. No. 11/052,261 filed Feb. 7, 2005, now U.S. Pat. No. 7,102,451, claiming priority to U.S. Provisional Application No. 60/545,359, filed on Feb. 18, 2004, and this application claims priority to U.S. Provisional Application No. 60/630,024, filed on Nov. 22, 2004, the disclosure of each application is hereby incorporated by reference in its entirety.

STATEMENT OF GOVERNMENT FUNDED RESEARCH

This work was supported by the Air Force Office Scientific Research FA9550-04-1-0199. Accordingly, the Government has certain rights in this invention.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the field of optically pumped atomic clocks, optically pumped atomic magnetometers, pulse laser systems, and more particularly to a laser that is self-modulated by alkali-metal vapor at 0-0 atomic-clock frequency by using light of alternating polarization referred to as push-pull optical pumping technique.

2. Description of the Related Art

Gas-cell atomic clocks and magnetometers use optically pumped alkali-metal vapors. Atomic clocks are applied in various systems that require extremely accurate frequency measurements. Atomic magnetometers are utilized in magnetic field detection with extremely high sensitivity. For example, atomic clocks are used in GPS (global positioning system) satellites and other navigation systems, as well as in high-speed digital communication systems, scientific experiments, and military applications. Magnetometers are used in medical systems, scientific experiments, industry and military applications.

A vapor cell used in atomic clocks or magnetometers contains a few droplets of alkali metal, such as potassium, rubidium, or cesium. A buffer gas, such as nitrogen, other noble gases, or a mixture thereof, is required to be filled inside the cell to match the spectral profile of the pumping light, suppress the radiation trapping, and diminish alkali-metal atoms diffusing to the cell wall. The gas cell is heated up to above room temperature to produce sufficient alkali-metal vapor. The resonances of alkali-metal ground-state hyperfine sublevels are especially useful for atomic clocks and atomic magnetometers. The hyperfine resonance is excited by rf (radio frequency) fields, microwave fields, or modulated light (CPT: coherent population trapping method). The resonance is probed by the laser beam. As shown in FIG. 1, hyperfine 0-0 resonance, ν_{00}, is particularly interesting for atomic clocks because of its insensitivity of the magnetic field at low field regime; hyperfine end resonance, ν_{end}, can be used either for atomic clocks and magnetometers; the Zeeman end resonance, ν_z, is usually used for a magnetometer because of its high sensitivity of the magnetic field. Besides the three illustrative resonances, other resonances of different hyperfine sublevels can also be used for atomic clocks and magnetometers. The resonance signal is reflected on the probing beam as a transmission dip or a transmission peak when the frequency is scanned through the resonance frequency. Conventionally, an atomic clock or a magnetometer measures the frequency at the maximum response of the atomic resonance. A local oscillator is required to generate the oscillation signal and excite the resonance. For a passive-type atomic clock, the frequency of the local oscillator is locked to the peak resonance as shown in FIG. 2. A precise clock ticking signal is therefore provided by the output of the local oscillator.

The development of atomic clocks and magnetometers is heading in the direction of low power consumption and compact size. To reduce the size and the complexity of the atomic clocks, the CPT method has been introduced for the atomic clock to get rid of microwave cavity. The conventional CPT method with fixed circularly polarized light and FM modulation suffers from the effects of population dilution and high buffer-gas pressure. Accordingly, it has a very small resonance signal. As for the power consumption of a conventional passive atomic clock, the local oscillator and the microwave circuitry can be a major draining source because of the complexity of the microwave circuitry and feedback loops of the passive-type atomic clocks. For a portable atomic-clock device, relatively high power consumption can reduce the battery lifetime and therefore decrease the utility of the miniature atomic clock.

It is desirable to provide an improved method and system for reducing complexity and power consumption of an atomic clock or magnetometer.

SUMMARY OF THE INVENTION

The problem of conventional CPT has been solved by Push-Pull pumping technique. Push-pull pumping can boost up the CPT signal by a significant factor and therefore effectively improve the performance of CPT atomic clocks. The present invention provides a method and apparatus for operating atomic clocks or magnetometers without a local oscillator and without an electronic feed-back loop for stabilizing the local-oscillator frequency. The atomic-clock signal is directly obtained from self-modulated laser light. The method and system is based on the physics of a push-pull optical pumping technique using an alkali-metal vapor cell placed inside a laser cavity to modulate the laser light at the frequency of the hyperfine resonance. In the laser cavity, a photonic gain medium, such as laser diodes or other kinds, can amplify the photon flux at different optical frequencies. Depending on the cavity configuration, optics may be needed to control the light polarization and the optical bandwidth. A fast photodetector can convert the modulated light into the clock ticking signal in electrical form with some optics.

A laser is a positive feedback amplifier of photons. An alkali-vapor cell inside the laser cavity operates similar to a photonic filter and converter to generate a special lasing mode, which produces the light modulation. Generally, a laser tends to lase in an optical mode, which has the maximum gain or the minimum loss of photons from their round-trip inside the cavity. Without the vapor cell, the lasing spectrum is determined by the characteristics of the laser cavity and the gain profile. With a vapor cell inside the cavity, a steady lasing point is met while the lasing spectrum produces the maximum efficiency of push-pull optical pumping, which makes the vapor cell become the most transparent. At this point, the output laser light is modulated at hyperfine frequency. If a 0-0 hyperfine resonance is